

IV. EARTHQUAKE

A. EARTHQUAKE HAZARD OVERVIEW:

Earthquakes have long been feared as one of nature's most damaging hazards. Earthquakes continue to remind us that nature still can strike without warning and, after only a few seconds, leave casualties and damage in their wake. Therefore, it is important that each person and community take appropriate actions to protect lives and property. This web site gives many suggestions for individual and community actions and provides links to web sites and publications with additional information. Although earthquakes cannot be prevented, current science and engineering provide tools that can be used to reduce their damage. Science can now identify, with considerable accuracy, where earthquakes are likely to occur and what forces they will generate. Engineering provides design and construction techniques so that buildings and other structures that can survive the tremendous forces of earthquakes. Individuals can take precautions around their home and work place to reduce the hazards from earthquakes.

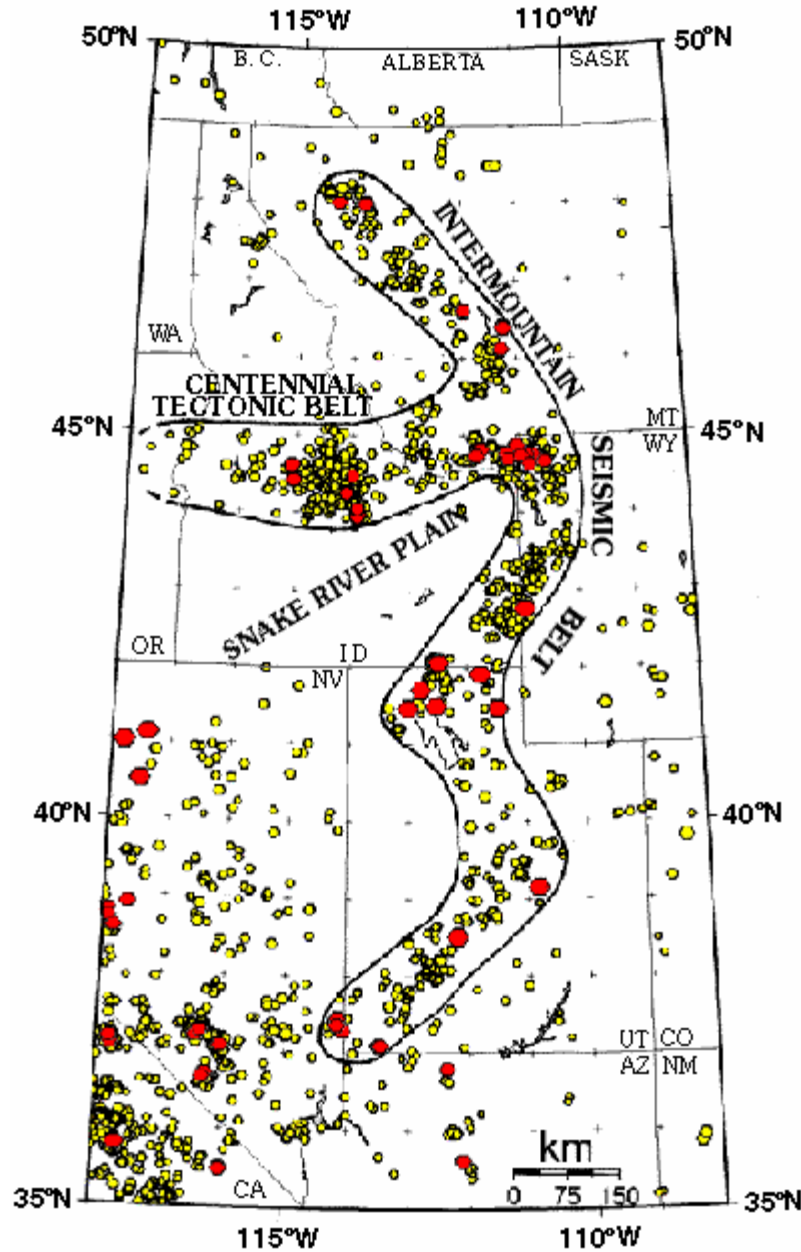
FEMA's Earthquake Program (Updated: March 21, 1999) has four basic goals directly related to the mitigation of hazards caused by earthquake. They are to:

- Promote Understanding of Earthquakes and their Effects
- Work to Better Identify Earthquake Risk
- Improve Earthquake-Resistant Design and Construction Techniques
- Encourage the use of Earthquake-Safe Policies and Planning Practices

B. DESCRIPTION

By far the greatest single-event natural hazard Montana faces is earthquakes. They may affect large areas, cause great damage to structures, cause injury, loss of life, and alter the socio-economic functioning of the communities involved (Working Group on Earthquake Hazards Reduction, 1978). The hazard of earthquakes varies by location, depending upon proximity to seismic sources and local geology. Western Montana contains a zone of high seismicity, the Intermountain Seismic Belt (Figure 1, page IV-2). The Intermountain Seismic Belt extends through western Montana, from the Flathead Lake region in the northwest corner of the state, to Yellowstone National Park region where the borders of Montana, Idaho, and Wyoming meet. The intermountain Seismic Belt continues southward through Yellowstone Park, along the Idaho-Wyoming border, through Utah, and into southern Nevada. In western Montana, the Intermountain Seismic Belt is up to 100 km wide. A branch of the Intermountain Seismic Belt extends west from the northwest corner of Yellowstone Park, through southwestern Montana, into central Idaho. This so called Centennial Tectonic Belt includes at least eight major faults and has been the site of the two largest historic

FIGURE:1 earthquakes in the northern Rocky Mountains, the August 18, 1959 Hebgen Lake, Montana, earthquake (M 7.5), and the October 28, 1983 Borah Peak, Idaho, earthquake (M 7.3). Although it has been over three and one half decades since the last destructive earthquake in Montana, small earthquakes are common in the region, occurring at an average rate over 5 earthquakes per day.

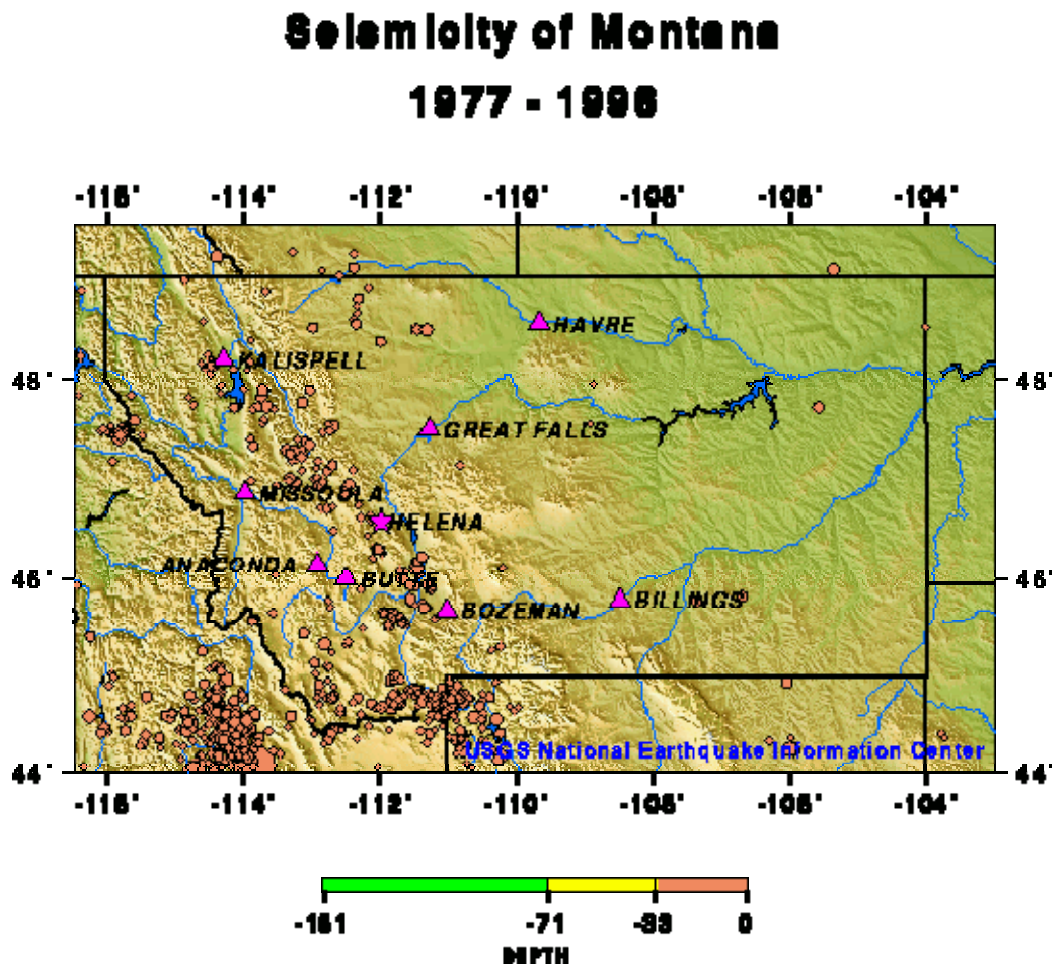


Earthquakes occur along faults--fractures in the earth's crust--when masses of rock slip suddenly past each other. When rocks in contact across a fault are forced to slide past each other, they do so in a "stick-slip" fashion; they accumulate strain energy for centuries or millennia, and then release it suddenly. The energy released radiates

outward from the source, or focus, as a series of waves that shake the ground. The two primary hazards of earthquakes result from ground shaking as seismic waves radiate in all directions from the focus, and from ground breaking where rupture along a fault plane meets the earth's surface. Secondary earthquake hazards result from damage to works of man and the effects of shaking on mountainous terrain and bodies of water.

The hazard of ground breaking is confined to a single fault or a narrow zone of multiple faults. Within a fault zone, which is generally less than 0.5 miles wide (Witkind, 1972), many structures may be destroyed and utilities cut. In the case of moderate, small or deep earthquakes, ground breaking will not occur at all.

Figure 2-Epicenters of earthquakes with magnitudes of 3.0 and greater (1900-1992) in the intermountain west. Shaded regions show the extent of the Intermountain Seismic Belt and the Centennial Tectonic Belt (from Stickney, 1995).



In contrast, ground shaking will affect broad regions surrounding the epicenter (the point on the ground surface above the focus). Ground shaking thus represents the greatest primary earthquake hazard. Because of their wide-ranging effects, large earthquakes in adjacent states pose shaking hazards to parts of Montana. Such was the case when a Lima, Montana school gymnasium was damaged to the degree of condemnation by the 1983 Borah Peak, Idaho earthquake (magnitude 7.3) centered 75 miles to the southwest. A strong earthquake may cause a seiche, the rhythmic sloshing of water in lakes or bays. This phenomenon occurred during the 1959 Hebgen Lake earthquake. Waves of water spilled over Hebgen Dam in response to the sudden tilting of the land surface that accompanied this magnitude 7.5 earthquake. A major landslide six miles downstream buried Highway 287, a campground with 26 people, and dammed the Madison River to form Earthquake Lake. Numerous other landslides occurred in the mountains within 50 miles of the 1959 epicenter (Hadley, 1964). Ground shaking can also change the mechanical properties of some fine-grained, water-saturated soils, whereupon they "liquefy" and temporarily behave like quicksand. The dramatic reduction in bearing strength of such soils can cause buried utilities to rupture and otherwise undamaged buildings to tilt or collapse.

The major form of damage from most earthquakes is damage to structures. Bridges are particularly vulnerable to damage. Even if a bridge remains in tact, strong seismic shaking may cause the approaches to settle or slump, thus rendering the structure impassable. Buildings vary in their susceptibility to ground shaking, depending on age, construction method, and soil type on which they are built. In general, older multi-story masonry buildings fare much worse than single story buildings of wood frame construction. All other things being equal, a building constructed on thick, unconsolidated soil will fare worse than a building on hard bedrock. Fires caused by ruptured gas mains may also destroy structures; a situation exacerbated by ruptured water mains.

Earthquakes are measured according to their intensity (observed effect) and magnitude (energy released). Intensity is an indication of an earthquake's strength of shaking at a specific location, as determined by experienced observers. For seismologists and emergency workers, intensity becomes an efficient, though subjective, shorthand for describing the effects of an earthquake in a given area.

The effect of an earthquake at the Earth's surface is described in terms of intensity. Designated by Roman numerals, it does not have a mathematical basis but instead is an relative ranking based on observed effects. The Modified Mercalli (MM) Intensity Scale was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. This scale is composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction. The maximum observed intensity generally, but not always, occurs near the epicenter.

The Modified Mercalli Intensity value assigned to a specific site after an earthquake has a more meaningful measure of severity to the nonscientist than the magnitude because intensity refers to the effects actually experienced at that place.

After the occurrence of widely felt earthquakes, the Geological Survey mails questionnaires to postmasters in the disturbed area requesting the information so that intensity values can be assigned. The results of this postal canvass and information furnished by other sources are used to assign intensity within the felt area. With the advent of the Internet, several websites allow citizens to contribute intensity observations and intensity maps are rapidly available.

The *lower* numbers of the intensity scale generally deal with the manner in which the earthquake is felt by people. The *higher* numbers of the scale are based on observed structural damage. Structural engineers usually contribute information for assigning intensity values of VIII or above.

In contrast to intensity, the magnitude of an earthquake is a number expressing the amount of energy released. Seismographic recordings of ground motion determine it. The Richter scale was the most commonly used magnitude scale in years past, but seismologists now favor a new magnitude scale that more accurately reflects the true size of an earthquake. Regardless of whether the new Moment Magnitude scale, or one of the several other magnitude scales in existence is used, they all share in common the fact that ground shaking increases by a factor of 10 for each increase of 1 magnitude unit. An earthquake of magnitude 7, for example, causes ground shaking ten times stronger than a magnitude 6 earthquake, 100 times stronger than a magnitude 5, and 1000 times stronger than a magnitude 4. There is no highest or lowest magnitude value, and it is possible here, as with temperature, to record negative values. The largest earthquake of record was rated at magnitude 9.5, while the smallest, about minus 3. Preliminary magnitudes reported in the hours following an earthquake may vary with the agency, equipment and method used in magnitude determination--the "final" magnitude assignment must await complete analysis of data from many seismograph stations, sometimes days or weeks later.

Magnitude and intensity measure different characteristics of earthquakes. Magnitude measures the energy released at the source of the earthquake. Magnitude is determined from measurements on seismographs. Intensity measures the strength of shaking produced by the earthquake at a certain location. Intensity is determined from effects on people, human structures, and the natural environment. Table 3 gives intensities that are typically observed at locations near the epicenter of earthquakes of different magnitudes.

Table 3 Magnitude and Intensity.

Magnitude	Intensity	Description
1.0 - 3.0	I	I. Not felt except by a very few under especially favorable conditions.
3.0 - 3.9	II - III	II. Felt only by a few persons at rest, especially on upper floors of buildings. III. Felt quite noticeably by persons indoors, especially on upper

		<p>floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.</p>
4.0 - 4.9	IV - V	<p>IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.</p> <p>V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.</p>
5.0 - 5.9	VI - VII	<p>VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.</p> <p>VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.</p>
6.0 - 6.9	VII - IX	<p>VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned.</p> <p>IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.</p>
7.0 and higher	VIII or higher	<p>X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.</p> <p>XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.</p> <p>XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.</p>

Source: *"Earthquakes and the Urban Environment", Vol. 1, G. Lennis Berlin, 1980*

Earthquakes release a tremendous amount of energy, which is why they can be so destructive. The table below correlates magnitudes with the approximate amount of TNT needed to release the same amount of energy.

Magnitude	Approximate TNT Energy
4.0	6 tons
5.0	199 tons
6.0	6,270 tons
7.0	199,000 tons
8.0	6,270,000 tons
9.0	99,000,000 tons

C. HISTORIC EARTHQUAKE OCCURRENCE/PREDICTION AND POTENTIAL

Although accounts of the explorers, Lewis and Clark hearing distant loud, rumbling sounds in the Great Falls area in 1805, have often been cited as evidence of early earthquake activity in Montana, the first confirmed earthquake in Montana was reported by D.S. Tuttle (1906) in 1869 in Helena. The strength of this quake caused houses to shake, overturning furniture and breaking dishes. Table 4 lists 31 significant earthquakes that have occurred in Montana since 1896. Ten earthquakes of magnitude 6.0 or greater since 1925 have caused damage or casualties. Although one significant earthquake struck in eastern Montana in 1909, most have occurred along the Intermountain Seismic Belt and Centennial Tectonic Belt in western Montana.

Table 4. Principal earthquakes in Montana 1869-1995 (Qamar and Stickney, 1983 and Stover and Brewer, 1991; values in parenthesis are estimated).

Date dy/mo/yr	Location (Hour and minute in parentheses)	Felt area (thousands of square km)	Modified Mercalli Intensity	Magnitude
10/12/1872	Deer Lodge	(30)	VII	(5.0)
06/09/1895	Butte	(30)		(5.0)
05/06/1897	South of Helena	(30)		(5.0)
04/11/1897	Dillon	(500)	VI?	(6.4)
15/05/1909	Eastern Montana	1300	VI?	6.5
19/04/1910	Butte	(70)		5.4
27/06/1925	Clarkston Valley	803	VIII	6.8
10/08/1925	Sweet Grass	65	V	(5.3)
12/12/1926	Three Forks	78	V	(5.4)
15/02/1929	Lombard	104	V	(5.6)
12/10/1935	Helena	181	VII	(5.9)
18/10/1935	Helena	596	VIII	6.3
31/10/1935	Helena	363	VIII	6.0
28/11/1935	Helena	233	VI	(6.0)
23/09/1945	Flathead Lake	93	VI	(5.5)
23/11/1947	Virginia City	388	VIII	6.3
31/03/1952	Big Fork	91	VII	(5.5)
17/08/1959	Hebgen Lake	1554	X	7.5
18/08/1959	Hebgen Lake(00:56)			6.5
18/08/1959	Hebgen Lake(01:41)		VI	6.0
18/08/1959	Hebgen Lake(04:03)			5.6
18/08/1959	Hebgen Lake(08:26)			6.5
18/08/1959	Hebgen Lake(21:04)		V	6.0
19/08/1959	Hebgen Lake		V	5.0
21/10/1964	Hebgen Lake	65	V	5.8
05/01/1965	Dillon	31	VI	5.1
01/07/1974	Hebgen Lake			5.1
03/02/1975	Kalispell	50	VI	5.0
11/03/1977	Hebgen Lake		IV	5.2
01/04/1985	Seeley Lake	68	V	4.8
09/11/1985	Hebgen Lake		V	4.8

After reviewing historic earthquakes throughout the Great Basin and Intermountain Seismic Belt, DePolo (1994) concluded that earthquakes smaller than magnitude 6.5 seldom produce surface rupture. Thus, regions characterized by frequent or persistent micro earthquake activity should be considered capable of generating earthquakes with magnitudes as large as 6.5, even though active faults are not known to be present at the earth's surface. A brief review of historical earthquake follows. Coffman and others (1982) and Qamar and Stickney (1983) give a more detailed account of historical earthquakes in Montana.

Northwest Montana

Seismicity at the northern end of the Intermountain Seismic Belt has been concentrated around Flathead Lake as episodes of earthquake activity in 1945, 1952, 1964, 1969, 1971, 1975, and 1995. These episodes are often swarms of earthquakes (groups of earthquakes clustered in time and space, lacking a single earthquake of outstanding magnitude) with maximum magnitudes of 5.0-5.5. However, the February 4, 1975 (magnitude 5.0) and May 2, 1995 (magnitude 4.5) earthquakes were typical main shock earthquakes followed by aftershocks. Over the past 50 years, earthquakes have occurred primarily west and north of Flathead Lake (Stevenson, 1976, Stickney, 1980, and Qamar and others, 1982), but apparently not along the Mission fault, the large, north-south trending fault along the eastern edge of Flathead Lake at the foot of the Mission Range.

Despite an apparent lack of earthquakes over the past century, the Mission fault shows conclusive evidence of major prehistoric earthquakes. Ostenaa and others (1995) present evidence from trenches excavated across the Mission fault indicating the occurrence of a magnitude 7.5 earthquake that ruptured the southern Mission fault between the latitudes of Pablo and St. Mary's Lake (a distance of 45 km) approximately 7700 years ago. Additional evidence indicates a similar sized earthquake also occurred 12,000-15,000 years ago. Thus, the Mission fault is active and capable of generating infrequent but potentially devastating earthquakes. Ostenaa and others (1990) also discovered evidence of geologically recent movement on the Jocko fault, just north of Missoula.

West-central Montana

A zone of ancient faulting extends west-northwest from Helena, through Missoula, nearly to Spokane, Washington. This so called Lewis and Clark zone is up to 40 miles wide and includes over a dozen major faults. Recent earthquake activity occurs primarily in the eastern half of the Lewis and Clark zone between Missoula and Helena (Stickney, 1978). The Jocko fault just north of Missoula and several faults in the Helena Valley are the only Lewis and Clark zone faults with recognized surface evidence of major earthquakes in the past few tens of thousands to hundred fifty thousand years, and are thus considered active (Stickney and Bartholomew, 1987 and Ostenaa and others, 1990).

At least two different faults at the eastern end of the Lewis and Clark zone in the Helena Valley were responsible for the destructive 1935 Helena earthquakes although neither has been identified. The Helena earthquakes began with a magnitude 5.8 shock on October 12 that caused some damage in Helena. A magnitude 6.3 earthquake followed on October 18 and a magnitude 6.0 quake on October 31. The two largest earthquakes resulted in four casualties and an estimated \$4 million in damage (Coffman and others, 1982). The strong seismic shaking damaged over 60 percent of the buildings in Helena, interrupted electrical power, and caused minor ground liquefaction

in areas along Prickly Pear Creek. Numerous smaller quakes continued for months--over 1800 earthquakes were felt by Helena residents from October 12, 1935 to April 30, 1936 (Scott, 1936). A sequence of smaller earthquakes struck Helena in 1945 but did not cause significant damage. Additional moderate earthquakes have occurred in the region between Helena and Ovando during the past two decades.



Helena, Montana Earthquake, Magnitude 6.19: Bryant School OCT 18, 1935, Steinbrugge Collection, Earthquake Engineering Research Center, University of California, Berkley.



Helena, Montana Earthquake, Magnitude 6.19: Helena High School OCT 18, 1935, Steinbrugge Collection, Earthquake Engineering Research Center, University of California, Berkley.

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Southwest Montana

Of all regions in Montana, southwest Montana has produced the greatest number of large, historic earthquakes, and has the greatest number of active faults. It is thus reasonable to suspect this region of the state as the most likely to experience future destructive earthquakes. An earthquake with estimated magnitude of 6.4 struck the Dillon area in 1897 but little is known about this event owing to the sparse population of the time.

Montana's first destructive quake occurred in the early evening hours of June 27, 1925 and was centered just north of Three Forks along the Missouri River in the Clarkston Valley. This magnitude 6.8 earthquake destroyed several churches and schools in the surrounding towns of Three Forks, Logan, and Manhattan, and damaged buildings as far away as Bozeman, White Sulphur Springs, and Butte (Pardee, 1926). Strong shaking dislodged boulders and rockslides, burying tracks of both the Northern Pacific and the Chicago, Milwaukee & St. Paul railroads along the Missouri River and Sixteen Mile Creek. Extensive ground cracking and liquefaction was observed in bottomlands along the Missouri River. A large aftershock with an estimated magnitude of 6.0 occurred 49 minutes after the main shock. Despite the large magnitude of the 1925 quake and the wide-ranging effects, the location of the causative fault was not positively identified as it apparently did not rupture through to the earth's surface. The Three Forks region--and Clarkston Valley in particular--has produced several earthquakes in the magnitude 4-5 ranges over the past several decades (Qamar and Hawley, 1979) and remains very active at the micro earthquake level (Stickney, 1995).

The Hebgen Lake region is by far the most seismically active region of the entire state and the most seismically active region in the lower 48 states outside California and Nevada. Although earthquakes had been reported in the Hebgen Lake-Yellowstone National Park region since the late 19th century, the most destructive earthquake occurred just before midnight on August 27, 1959. The powerful Hebgen Lake earthquake (magnitude 7.5) generated nearly 20 miles of surface rupture on several faults, triggered numerous landslides and rock falls, and generated waves on Hebgen Lake large enough to overtop Hebgen Dam. Despite heavy damage from strong ground shaking and the overtopping waves, the Hebgen Dam did not fail. Had it done so, the loss of life and amount of destruction in the downstream regions would have been much greater. The largest landslide buried a campground in Madison Canyon resulting in the loss of 26 lives and damming the Madison River to form Earthquake Lake. Two other campers were killed by falling rock at Cliff Lake. Damage resulting from the 1959 earthquake was estimated at over \$11 million, most of that to roads and bridges. Damage at West Yellowstone, the closest town to the epicenter, included collapsed chimneys and some houses shifted off foundations but no fatalities. Thousands of aftershocks, some with magnitudes over 6.5 (see Table 4), followed the Hebgen Lake earthquake. A magnitude 5.8 earthquake occurred in the southern Madison Valley in 1964 and a magnitude 6.0 tremor shook Yellowstone Park in 1975. The Yellowstone Park-Hebgen Lake region continues to have small tremors virtually every week.

The Madison Canyon landslide, six miles below Hebgen Dam, was the most devastating result of this earthquake. Approximately 38 million cubic yards of rock slid to the canyon bottom, covered part of Rock Creek campground, blocked State Highway 287, and dammed the Madison River, causing Earthquake Lake to form. This landslide killed twenty-six people, but only seven bodies were found. The remaining 19 are presumed buried under the landslide.

Effects of the magnitude 7.51959 Hebgen Lake, MT earthquake.



Photo courtesy of the Deseret News



Photo #116 from I.J. Witkind Collection, U.S. Geological Survey
Courtesy of MT Bureau of Mines and Geology

The presences of major active faults in the Centennial Valley and Red Rock Valley along with the occurrence of frequent small earthquakes indicate that major earthquakes are also likely in the region west of Hebgen Lake and south of Dillon.

Eastern Montana

Eastern Montana is a region of relatively little seismicity. The most notable earthquake occurred in the extreme northeast corner of the state near the Saskatchewan-North Dakota border in 1909. Some estimates place the magnitude as high as 6.5 but it was most likely in the range of 5.5-6.0. The quake was felt well north in to Canada and as far west as Helena but no serious damage resulted, due in large part to the sparse population of the time. Several earthquakes in the magnitude 3.5-4.5 range have occurred in eastern Montana (Figure 1) over the past couple decades. Overall, eastern Montana is a region of low seismic hazard. However, the Brockton-Froid fault zone shows evidence of a major prehistoric earthquake.

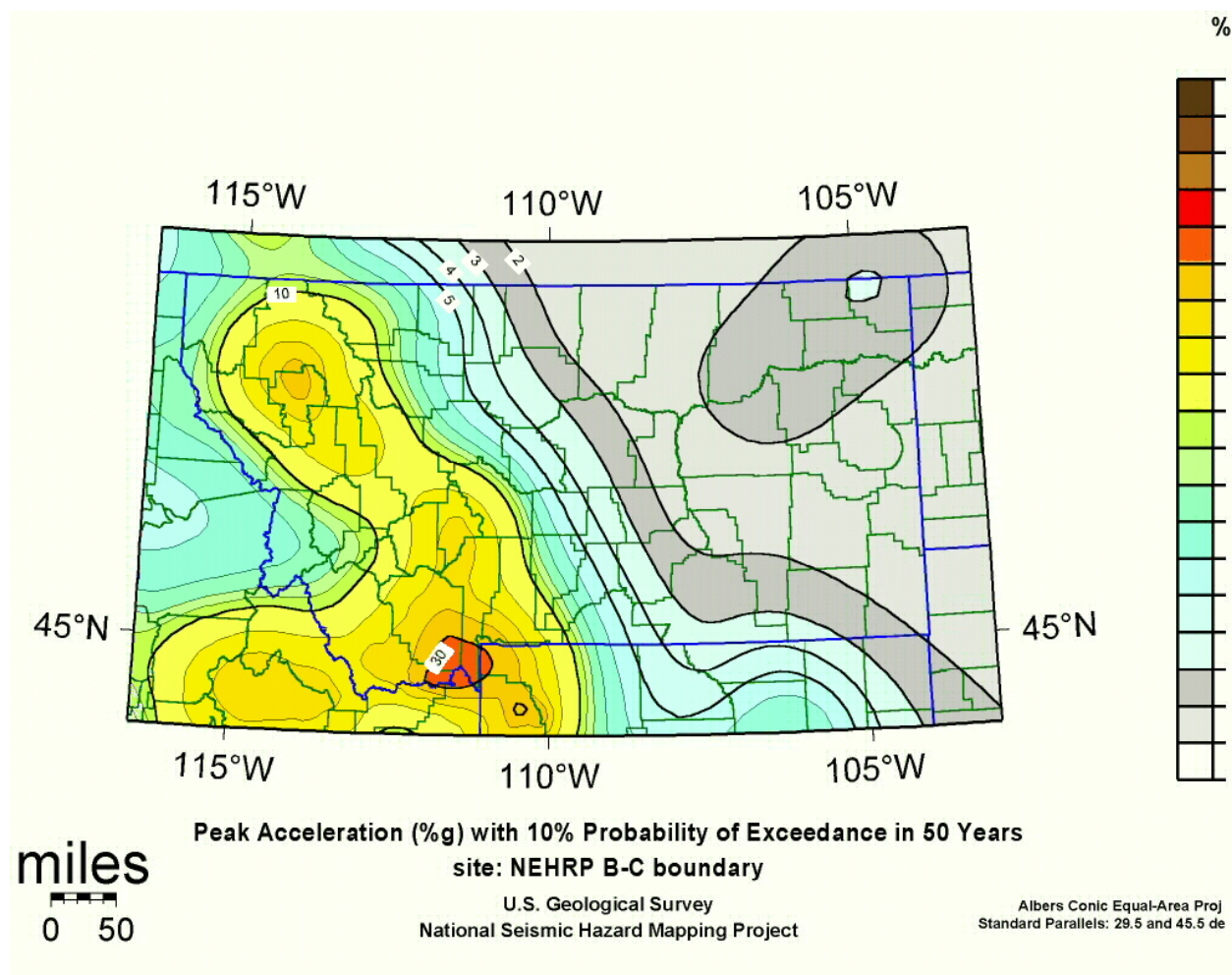
D. POTENTIAL FOR FUTURE EARTHQUAKES

Earthquakes will undoubtedly continue to occur in Montana, however the precise time, location, and magnitude of future events cannot be predicted. Major earthquakes (magnitude 6.5-7.5) may be expected to occur infrequently (every few hundred to few thousand years) along any one of the 25 or so recognized active faults in or adjacent to Montana. Lesser, but still potentially very damaging earthquakes (magnitude 5.0-6.5) may occur anywhere in western Montana within the Intermountain Seismic Belt or Centennial Tectonic Zone more frequently than major earthquakes.

An accurate estimate of the rate of occurrence of damaging earthquakes--the recurrence interval--is difficult to determine, in part due to the relatively short recorded history of Montana (less than 140 years) and even shorter period for which instrumental data are available (approximately 35 years). Also, the occurrence of damaging earthquakes has not been constant through time. During the 35 years from 1925 to 1960, a total of 12 earthquakes (including aftershocks) with magnitudes of 6.0 or greater have occurred in the Northern Rocky Mountains. The 35 years since 1960 have seen the occurrence of only one earthquake of magnitude 6.0 or greater in the same region. Thus, the rate of damaging earthquake occurrence seems to vary through the decades and the question of average return time remains to be answered.

The U.S. Geological Survey created a map of seismic hazards based on historic earthquake occurrence and the distribution of active faults. This map depicts the strength of shaking (expressed as a percentage of the acceleration of gravity) that has a 90% probability of not being exceeded over a 50-year period. Expressed another way, the mapped strength of shaking only has a 10% chance of occurring within a 50-year period.

Figure 3--Seismic hazard map of Montana from the U.S. Geological Survey hazard mapping project.



A standard procedure of analysis for estimating the frequency of earthquakes of various magnitudes in a given region involves plotting the number of earthquakes greater than or equal to a certain magnitude against that magnitude. A curve is fit to the data points falling along a linear trend. The equation of that line is then used to predict the number of earthquakes in various magnitude ranges. Such an analysis was applied to earthquakes cataloged by the Montana Bureau of Mines and Geology for the 14-year period 1982 through 1995. A total of 399 earthquakes occurring in western Montana (within a 275 km radius of 47°N, 112°W) ranging from magnitude 3.0 to 4.9 were analyzed. The results of this analysis are listed in Table 5. An inherent assumption in this analysis is that the seismicity for the period analyzed is representative of the long-term level of seismicity. As mentioned above, the last 14 years is part of a seismically quiet period for earthquakes of magnitude 5.0 and greater in Montana. This analysis suggests that a magnitude of 5.0 or greater should occur only once in a 15-year period. Because this analysis includes only earthquakes smaller than magnitude 5.0, great caution should be exercised when interpreting the return times of

larger earthquakes. Qamar and Stickney (1983) conducted a similar analysis using historic earthquake data up through 1977. From their analysis, an earthquake of magnitude 5.0 or greater was expected to occur somewhere in the northern Rocky Mountains once in a 14 year period. The 10-fold discrepancy between these two analyses points out the uncertainty with which we can forecast future rates of earthquake activity. The recurrence times listed in Table 5 probably represent lower limits for rates of future earthquake activity--the true rates of activity may be much greater. Despite these uncertainties, it is still true that future earthquakes are most likely to occur in zones of past earthquake activity--the inter- mountain Seismic Belt and the Centennial Tectonic Belt. In any case, it seems prudent to assume that a damaging earthquake may occur at least once during any decade.

Table 5. Annual observed and predicted frequency of earthquakes in western Montana based on 1982 -1995 seismicity.

<u>Magnitude</u>	<u>Observed</u>	<u>Predicted</u>	<u>(in years)</u>
3.0	28.5	35.6	.028
3.5	8.4	7.4	.14
4.0	1.9	1.5	.66
4.5	.21	.31	3.2
5.0		.065	15.3
5.5		.013	74.
6.0		.0028	358.
6.5		.00057	1733.
7.0		.00012	8374.

E. STATE VULNERABILITY TO EARTHQUAKES

The entire state of Montana is to some extent vulnerable to the effects of an earthquake. Montana has experienced many major earthquakes in the past. There is every reason to believe that similar events will occur in the future. Future earthquakes will occur where they have been recorded or where evidence is preserved of their prehistoric occurrence. Western Montana is more susceptible to a large earthquake than the eastern part of the state; however, a significant seismic event in eastern Montana is possible.

Numerous factors contribute to determining an areas vulnerability: historical earthquake occurrence, proximity to faults, soil characteristics, building construction, and population density, to mention a few. Considering both population concentration and historic seismicity, Helena and Bozeman are the most vulnerable locations, followed by Missoula, Butte and Kalispell. Moreover, 47% of Montana's 2000 population resides in the 16 western Montana counties within high hazard seismic zones. These same counties have experienced growth in population. Seasonal tourism increases

exposure to seismic hazards in all areas, but the greatest exposure is in the Yellowstone National Park-Hebgen Lake region where several million people visit annually. The fact that the majority of the 28 fatalities associated with the 1959 Hebgen Lake earthquake were out of state visitors confirms this point. In contrast, Great Falls and Billings, the two largest cities in the state have relatively low earthquake hazards.

A belt of seismicity known as the Intermountain Seismic Belt extends through western Montana, from the Flathead Lake region in the northwest corner of the state to the Yellowstone National Park region where the borders of Montana, Idaho, and Wyoming meet. The Intermountain Seismic Belt continues southward through Yellowstone Park, along the Idaho-Wyoming border, through Utah, and into southern Nevada. In western Montana, the Intermountain Seismic Belt is up to 100 km wide. A branch of the Intermountain Seismic Belt extends west from the northwest corner of Yellowstone Park, through southwestern Montana, into central Idaho. This so called Centennial Tectonic Belt includes at least eight major active faults and has been the site of the two largest historic earthquakes in the northern Rocky Mountains, the August 18, 1959 Hebgen Lake, Montana, earthquake (M 7.5), and the October 28, 1983 Borah Peak, Idaho, earthquake (M 7.3). Although it has been over three and one half decades since the last destructive earthquake in Montana, small earthquakes are common in the region, occurring at an average rate of 2-3 earthquakes per day.

<http://mbmgsun.mtech.edu/eqstats.htm>

The major form of damage from most earthquakes is damage to construction. Bridges are particularly vulnerable to collapse, and dam failure may generate major downstream flooding. Buildings vary in susceptibility, dependent upon construction and the types of soils on which they are built. Fires caused by ruptured gas mains may also destroy structures.

The damage caused by both ground breaking and ground shaking can lead to the paralysis of the local infrastructure: police, fire, medical and governmental services. As with many catastrophes, the worst hazard to the survivors is their own shock and inability to respond to the necessity for prompt, effective action.

F. MITIGATION

By assessing earthquake potential, precautions may be taken to reduce or avoid major tragedy and loss of life in Montana. The Montana Bureau of Mines and Geology operates a network of seismograph stations in western Montana. Data from this network is used to inform emergency personnel of significant earthquakes, study small earthquakes that define the tectonic stresses acting on Montana, characterize source zones of potentially destructive earthquakes, and for education and increasing public awareness. Additional studies have defined the locations and prehistoric seismicity of active faults. Detailed geologic mapping helps to identify areas, especially in heavily populated regions, where local soil conditions may enhance and amplify seismic shaking.

Data from these sources add significantly to knowledge in the field of earthquake hazard mitigation. This knowledge can be applied in planning to mitigate the effects of an earthquake, see section H of this annex.

The MBMG has received funding from FEMA to mitigate the effects of future earthquakes. Six separate tasks are scheduled to enhance the Earthquake Studies Office's ability to record and rapidly provide accurate information following significant earthquakes and educate the public about earthquake hazards. Tasks include:

- 1) Publish a new map showing active faults in western Montana;
- 2) publish a pamphlet describing earthquake hazards and measures that citizens can take in the home and work place to mitigate these hazards;
- 3) construct a traveling display illustrating hazards, historic earthquakes and their effects, and hazard mitigation measures;
- 4) become a member of the Incorporated Research Institutions for Seismology;
- 5) install a non-interruptible power supply for the Earthquake Studies Office; and
- 6) install a new broadband seismograph in cooperation with the U.S. National Seismic Network. These tasks are scheduled for completion by 2001.

G. SUMMARY

Montana has experienced several destructive earthquakes, although none have occurred since 1960. Frequent small earthquakes and numerous active faults, together with a history of damaging earthquakes illustrate the fact that significant future earthquakes in Montana are likely. Western Montana is more susceptible to a large earthquake than eastern Montana; however, the 1909 earthquake demonstrates that the eastern part of the state is not immune to earthquakes. Southwest Montana, especially the Yellowstone-Hebgen Lake and Three Forks-Helena areas are most likely to suffer future damaging earthquakes.

Many researchers have unsuccessfully tried to forecast earthquake occurrence. Even guessing that an event will occur within six months cannot be done with any degree of accuracy. Predicting the area where an earthquake will happen is an easier, more reliable task. Since earthquakes are usually associated with faulting, any region containing active faults is potentially dangerous. Unfortunately and inexplicable, earthquakes also strike within zones that do not contain faults, and, because the community is unaware of the potential hazard, extensive damage often occurs. The implementation of these mitigation strategies requires education of the people and their government to the risks and alternatives.

H. RECOMMENDATIONS: Earthquake mitigation may be advanced in many of the following areas:

- 1) Earthquake risk zones should be mapped, at a scale that allows local government decision-makers to implement defensible land-use planning, zoning and subdivision regulations.
- 2) The seismic monitoring network should be upgraded and expanded to provide modern seismic monitoring capabilities to all communities in the western part of the state as well as modest monitoring capabilities in eastern Montana.
- 3) Regulations should require that critical public buildings (i.e. schools, hospitals, nursing homes) in earthquake prone areas be constructed to withstand the maximum credible seismic shaking, even though those construction standards may exceed existing uniform building code standards.
- 1) Research is needed in the development of reliable warning systems for associated hazards such as dam failure.
- 1) Retrofit schools and other facilities interior windows with shatterproof Mylar film.
- 2) Pre-event planning and exercising which coordinates all responding agencies is critical.
- 3) As is the case with all potential hazards, public education is essential to effective mitigation. The public should be educated about earthquake probability and effects as well as measures that will protect them and property.

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